DURIP: Side Scan Sonar and Inertial Navigation System for AUV-Based Ocean Bottom/Sub-Bottom Mapping for Object Search/Identification

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LONG-TERM GOALS

The long-term goals of this project are to fully equip our Bluefin 21 autonomous underwater vehicle (AUV) with acoustic imaging and navigation systems to permit very wide band, high resolution, repeat mapping studies of the ocean bottom and sub-bottom. These types of basic science studies have direct application to mine countermeasures, detection of bottom scour patterns for ASW missions, studies of the nature and evolution with time of fine-scale structures on the ocean bottom, general seafloor surveys for bottom deployments, seafloor geohazards, and vehicle precision navigation.

OBJECTIVES

The objectives of the work supported under this DURIP are to acquire and integrate a set of acoustic imaging and navigation systems into the Bluefin 21 AUV operated by the Marine Physical Laboratory, Scripps Institution of Oceanography (MPL/SIO). The purpose is to be able to conduct autonomous repeat mapping surveys of the ocean bottom and sub-bottom to search for changes in properties with time. The acoustic imaging systems have resolution on a wide range of spatial scales down to the decimeter level. Previous research efforts have demonstrated that the AUV can be navigated in absolute space to decimeter-level accuracy using a special-design high-precision acoustic navigation system (Kussat *et al*, 2005). Therefore, the goal is to develop an autonomous mapping capability with decimeter level repeatability.

APPROACH

The original approach presented in the DURIP proposal was to acquire a fiber-optic-gyro-based inertial navigation system (INS) and an payload midsection with syntactic foam, along with a combination side scan sonar and sub-bottom profiler system for our Bluefin 21 AUV (Figure 1). However, after the proposal was submitted, funds were obtained to purchase an INS as part of a joint program between the Scripps Institution of Oceanography and British Petroleum. In addition, a payload midsection and syntactic foam were acquired by other means. Therefore, the approach now

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14. ABSTRACT
The long-term goals of this project are to fully equip our Bluefin 21 autonomous underwater vehicle (AUV) with acoustic imaging and navigation systems to permit very wide band, high resolution, repeat mapping studies of the ocean bottom and sub-bottom. These types of basic science studies have direct application to mine countermeasures, detection of bottom scour patterns for ASW missions, studies of the nature and evolution with time of fine-scale structures on the ocean bottom, general seafloor surveys for bottom deployments, seafloor geohazards, and vehicle precision navigation.

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being taken is somewhat modified from that proposed. The combination side scan sonar (SSS)/sub-bottom profiler (SBP) from EdgeTech, the most expensive component in the proposal, still is being acquired, as originally proposed. This full spectrum chirp SSS operates at the dual frequencies of 120 kHz and 410 kHz, and the SBP operating frequency band is 1-6 kHz. The remaining funds are being redirected to acquire additional acoustic imaging systems. One system that already has arrived in-house is a new-design multibeam sonar system specifically made for AUVs by Imagenex Technology Corp. This multibeam system is a model 837 Delta T profiling sonar with an operating frequency of 260 kHz, a maximum depth rating of 6000 m, a cross-track angular resolution of 0.75 deg over a 120-deg interval, and 3-deg resolution along-track. Its weight, size, and cost are several times smaller than existing multibeam systems. Another sonar system being purchased is an obstacle avoidance sonar from Tritech International Ltd. It will allow surveys of ocean bottoms and sub-bottoms in regions with rapid changes in bathymetric relief. Tritech's Micron Sonar operates at a range of tunable frequencies from 650 kHz to 950 kHz, has a nominal 30-deg vertical beamwidth and 2.5-deg horizontal beamwidth, and is extremely compact (5.6 cm by 6.7 cm by 7.9 cm).

A key aspect of the approach is to leverage the development of the AUV acoustic imaging and navigation systems acquired under this grant to the maximum extent possible with other ongoing and proposed programs at MPL/SIO. One such program is the Seafloor Geohazards project, a joint effort between SIO and British Petroleum. The purpose of this project is to develop technologies to measure seafloor changes and deformation down to the millimeter level over areas ranging from 0.5 to tens of kilometers and on time scales of a few weeks to several years. These measurements are required to better evaluate the potential hazards to subsea operations posed by seafloor instability. The project is composed of three components, the fiber-optic strain sensor (FOSS) component, the acoustic geodesy component, and the AUV repeat-mapping component. The FOSS system measures changes in the length of a fiber-optic cable stretched between two seafloor anchors to an accuracy of 1 mm or less. Sensors with baselines of 0.5, 0.75, and 1.0 km will be deployed in the Goleta Slide region south of Santa Barbara, CA, a region believed to be undergoing active deformation. Co-deployed with the FOSS sensors will be a net of seafloor transponders and acoustic nodes to measure the round-trip travel times of acoustic pulses between all possible pairs. This net, comprising the acoustic geodesy component, will measure centimeter-level relative horizontal displacements over spatial scales of a few kilometers. The transponder net also will provide the basis for the high precision, long-baseline-navigation (LBL) system for the AUV bottom repeat mapping effort. The LBL navigation system will be supplemented by the AUV's internal navigation systems, centered on its fiber-optic-gyro inertial navigation system, to provide a repeat mapping capability outside the transponder net.

The efforts funded under this DURIP also are being leveraged with the Persistent Littoral Undersea Surveillance Network (PLUSNet) program, part of the Office of Naval Research's (ONR) Code 32 6.2 Discovery and Invention research program. A total of seven academic institutions participate in PLUSNet including MPL/SIO, the Applied Physics Laboratory, University of Washington, the Applied Research Laboratories, University of Texas at Austin, the Applied Research Laboratories, Penn State University, the Massachusetts Institute of Technology, Woods Hole Oceanographic Institution, and Harvard University. In addition, one U.S. Navy laboratory (the SPAWAR Systems Center, San Diego) and four companies (Science Applications International Corp., Bluefin Robotics, Corp., Metron, Inc., and Heat, Light, and Sound, Inc.) are part of the program. The objective of this 3-year program is to develop a semi-autonomous controlled network of fixed bottom and in-water mobile platforms (both prop-driven AUVs and underwater gliders) using environmentally and tactically adaptive processing to enhance the detectability and tracking of quiet submerged targets in shallow water environments of operational interest. As part of PLUSNet, MPL/SIO will continue the development of quiet low-noise thrust systems and hull-mounted passive acoustic arrays for Bluefin 21

AUVs previously begun using MPL/SIO's Odyssey IIb AUV (Zimmerman *et al*, 2005). The at-sea engineering tests of the AUV in PLUSNet will be highly leveraged with those required under this DURIP.

A recently completed DoD-funded research program is the Passive Synthetic Aperture Sonar (PasSAS) program, part of the Office of Naval Research 6.1 Applied Research Laboratory program managed by Code 321(US). The objective of the program was to examine both experimentally and theoretically the benefits of passive synthetic aperture sonar (PasSAS) for use in undersea warfare. The receiving platform used to create the synthetic aperture was our older-design Odyssey IIB AUV formerly sold by Bluefin Robotics, Inc. An idea that has been demonstrated by the results of this program is that autonomous underwater vehicles used as passive acoustic receivers have the ability to modify the structure of the received acoustic field in order to optimize extraction of information of interest, e.g., the directionality of the field (D'Spain *et al*, 2005). From this point of view, the characteristics of the receiving vehicle becomes an integral part of the signal and array processing, and can be incorporated into the processing structure in a formal way. In order to permit the hydrophone array mounted on the inner shroud of our AUV to passively measure the low-frequency underwater sound field, the radiated acoustic and vibration noise of the AUV's thrust system was decreased by up to 50 dB. This self noise-quieting effort also will be quite beneficial in improving the acoustic images obtained by the AUV's active sonar systems.

Results from the High-Frequency/Mid-Frequency (HF/MF) Passive Processing program sponsored by ONR Code 321(US) demonstrate that naturally occurring ocean acoustic noise in the HF (10-20 kHz) and MF (1-10 kHz) frequency bands as measured by large vertical aperture arrays (order 15 acoustic wavelengths in length) can be used to obtain detailed information on the geophysical properties of the ocean bottom. An AUV equipped with full spectrum acoustic profiling systems, as is being developed under this DURIP, will allow ground truth information on bottom and sub-bottom properties to be readily acquired to verify the ambient noise results.

Autonomous vehicle technology is revolutionizing U.S. Navy operations (The Navy UUV Master Plan, 2004). These points are illustrated by the success of prop-driven AUVs for addressing the mine countermeasure problem and the rapidly expanding use of existing gliders for long-duration sensing of oceanographic fields. The technology also is revolutionizing oceanographic research. Capitalizing on the advances, we are teaming with U.S. Coast Guard personnel in their ice-breaker program and other AUV user groups in the U.S. to join an international team of scientists addressing several basic science questions associated with the impact of global warming on the oceanography, geophysics, and ecology of the Antarctic region (McGillivary *et al*, 2005). This 3-year effort starting in 2007 is part of the International Polar Year. The MPL/SIO Bluefin 21 AUV equipped with precision navigation and acoustic imaging systems will be one of the major data acquisition platforms in this international, multi-institutional program.

The Deep Tow Systems Group at the MPL/SIO provides the engineering support for operating and maintaining the mid-size, prop-driven autonomous vehicles, as well as the 20-ft span Liberdade/XRay flying wing glider. This group has a long history in developing innovative capabilities with ROV and AUV platforms. For example, the group developed in the 1960's the very first instrument package deployed from a ship and towed at depths just above the seafloor. This development not only met important Navy needs, but also led to several important scientific discoveries such as the original discovery of the biology surrounding deep sea hydrothermal vents. During the past three years, the group has applied its expertise to collecting high-quality passive acoustic data with a hull-mounted hydrophone array on our Odyssey IIB AUV as part of the PasSAS program discussed above. During

its work with autonomous vehicles, the group has formed a close working relationship with the AUV program at the Monterey Bay Aquarium and Research Institute (MBARI) and with Bluefin Robotics, a major manufacturer of prop-driven AUVs.

WORK COMPLETED

An INS, a model U-PHINS fiber-optic-gyro-based system manufactured by iXSea Corp in France, was purchased with 2004 year-end funds in the joint Scripps/BP program. It arrived in-house in July after recalibration. A meeting was held with the Bluefin Robotics software engineers during the summer to determine how to fully integrate the INS into the vehicle. This effort will take advantage of Bluefin's experience in integrating an iXSea INS into a Bluefin 21 for the NATO Undersea Research Centre. However, it will require a change to the newest AUV operating software, which will occur with Bluefin's assistance sometime this fall. We conducted a wide-ranging search for the types and models of acoustic imaging systems appropriate for mid-size AUVs. The most promising systems were incorporated into a 3D structural engineering design model to determine the most effective packing arrangement in the AUV payload midsection. One of these models is presented in Fig. 2. It shows the locations of the INS, the high-precision acoustic navigation system, the Imagenex multibeam profiling sonar and its data acquisition system, and a DIDSON acoustic camera (www.didson.com). Price quotes for these, and other, systems with the desired specifications have been obtained. A 6000-m-rated Imagenex 837 Delta T profiling sonar was ordered and arrived in-house in July. The design for its data acquisition system is finished and components are being ordered. The order form for the TriTech Micron obstacle avoidance sonar has been submitted. Finally, other than the desired cabling geometry, all the specifications for the combination EdgeTech SSS/SBP system and topside processing system have been identified and the order will be submitted in the near future.

RESULTS

The AUV with its new operating software system, fully integrated INS, Imagenex multibeam profiling sonar and data acquisition system, and high-precision acoustic navigation system will be tested at sea in December, 2005. Results from the repeat-bottom-mapping efforts using the Imagenex sonar with the AUV deployed at various altitudes above the ocean bottom will be available shortly after this experiment. The additional acoustic imaging systems will be integrated into the AUV in the first few months of 2006 and tested at sea in spring, 2006.

IMPACT/APPLICATIONS

The relevance of developing AUV technology for the Navy's mission is detailed in the Navy UUV Master Plan (2004). Specifically for this DURIP, a mid-size AUV equipped with acoustic imaging and navigation systems to permit very wide band, high resolution, repeat mapping studies of the ocean bottom and sub-bottom has direct application to mine countermeasures, detection of bottom scour patterns for ASW missions, studies of the nature and evolution with time of fine-scale structures on the ocean bottom, general seafloor surveys for bottom deployments, seafloor geohazards, and vehicle precision navigation. This AUV with instrumentation acquired under this DURIP will provide a very useful platform for a large number of future basic research programs in the areas of geophysics, ocean acoustics and undersea signal processing, autonomous vehicle technology, oceanography, climate change, and marine biology.

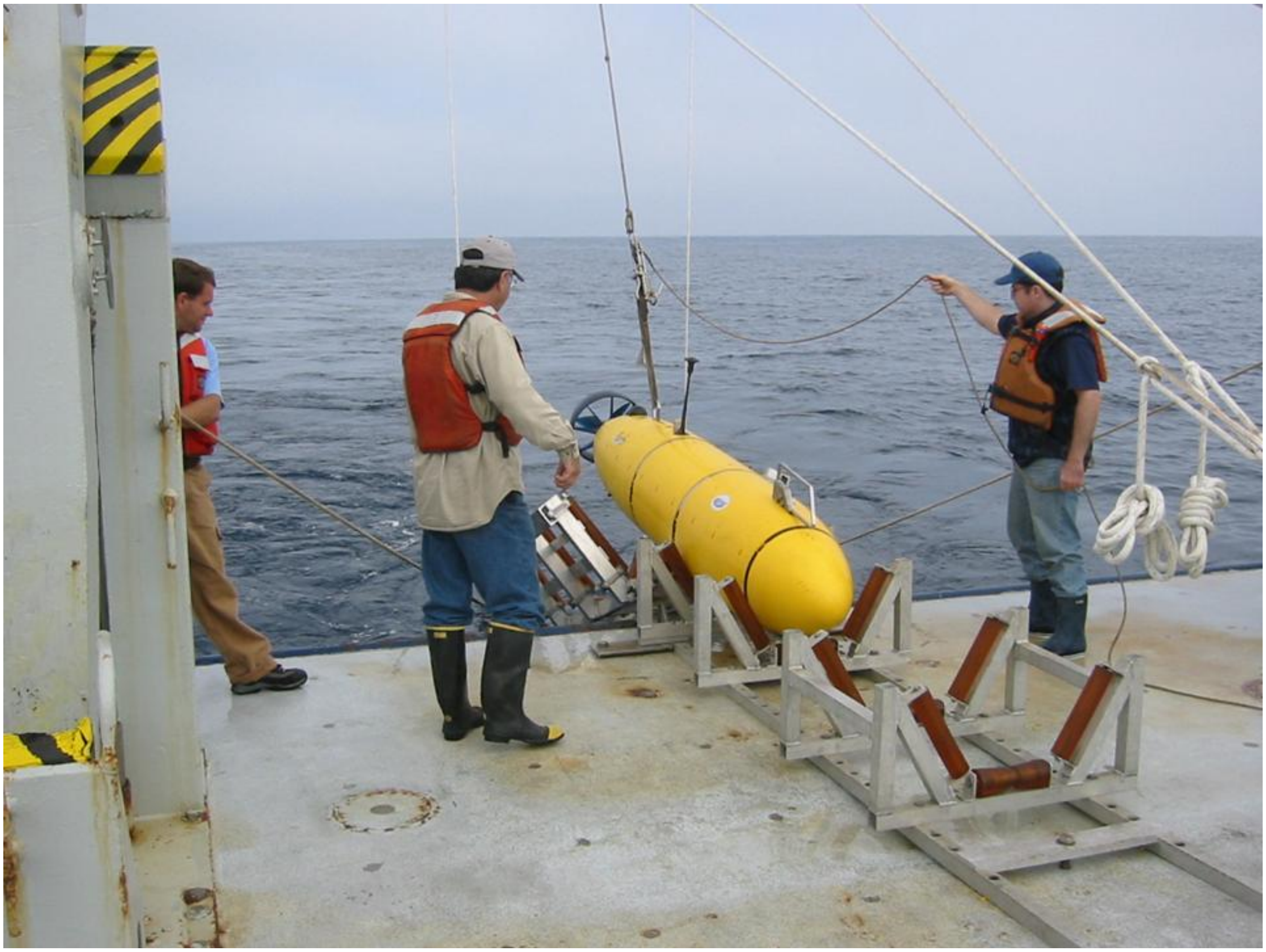

Figure 1 : A photograph of the deployment of MPL/SIO's Bluefin 21 AUV from the fantail of the R/V Sproul.

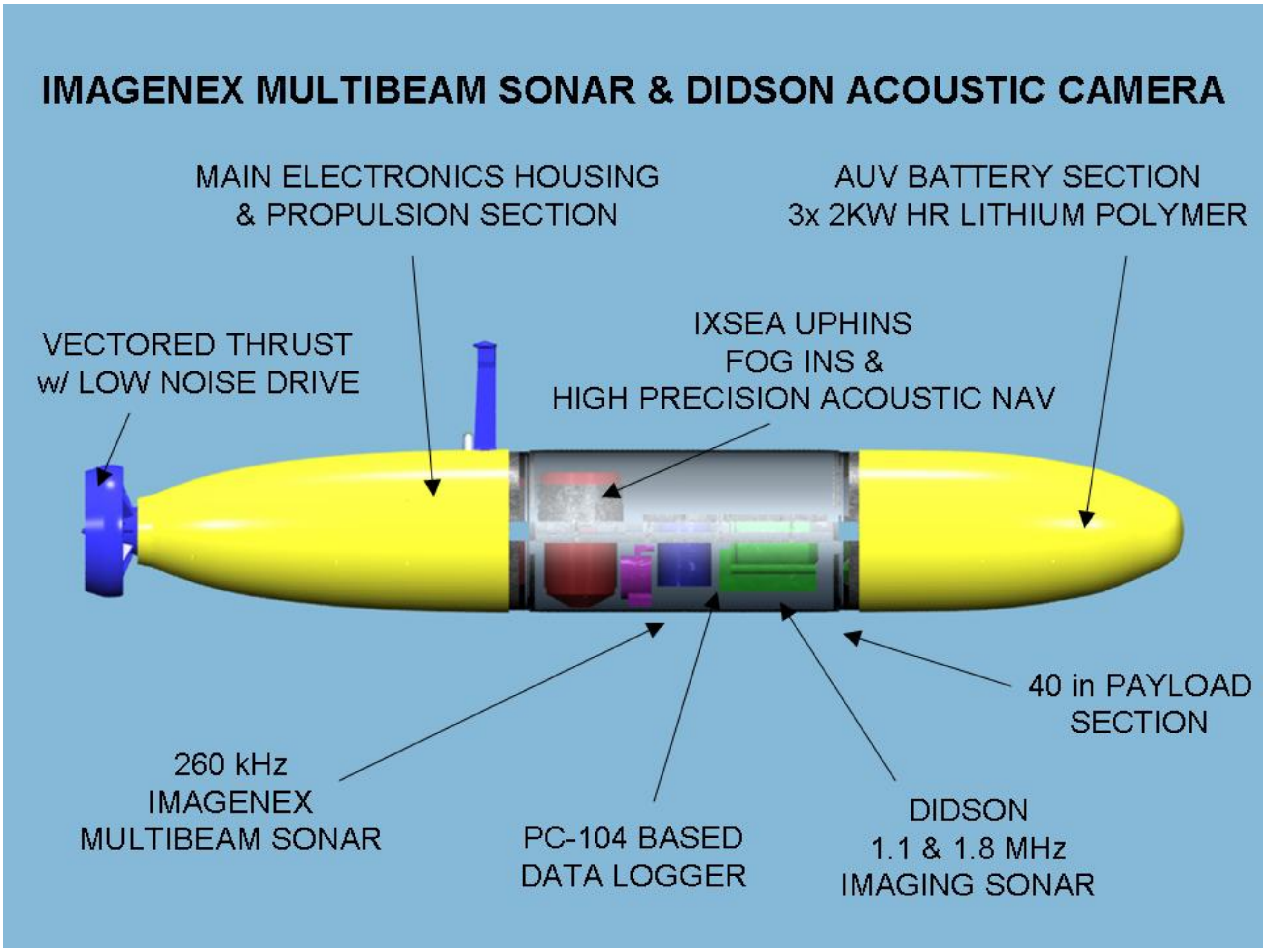

Figure 2 : A schematic of the packing arrangement in a Bluefin 21 AUV 40-inch payload midsection of the iXSea INS, the high-precision acoustic navigation system, the 260 kHz Imagenex multibeam profiling sonar and PC-104-based data acquisition system, and DIDSON acoustic camera.

RELATED PROJECTS

- The joint Scripps-British Petroleum Geohazards program, sponsored by British Petroleum, is developing technologies to measure seafloor changes and deformations to the millimeter level for application to evaluation of potential seafloor geohazards evaluation.

- The PLUSNet program, sponsored by ONR Code 32, is developing a prototype semi-autonomous network of fixed and mobile platforms, including prop-driven AUVs, using environmentally and tactically adaptive processing to enhance the detectability and tracking of quiet submerged targets.

- The Applied Research Laboratory program, managed by ONR Code 321(US), is developing signal and array processing algorithms for use with autonomous underwater vehicles.

- The “HF/MF Passive Processing” program, sponsored by ONR Code 321(US), is developing signal and array processing algorithms for use with large aperture, high-frequency and mid-frequency billboard arrays for application to passive hull-mounted sonar systems and autonomous systems.

- The “Flying Wing Underwater Glider for Persistent Surveillance Missions” program, a partnership between MPL/SIO and APL/UW sponsored by ONR Code 321(OE), is developing a new class of underwater glider based on a flying wing design (Jenkins *et al*, 2005). Some of the navigation systems and the obstacle avoidance sonar for this glider are the same as for our Bluefin 21 AUV.

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